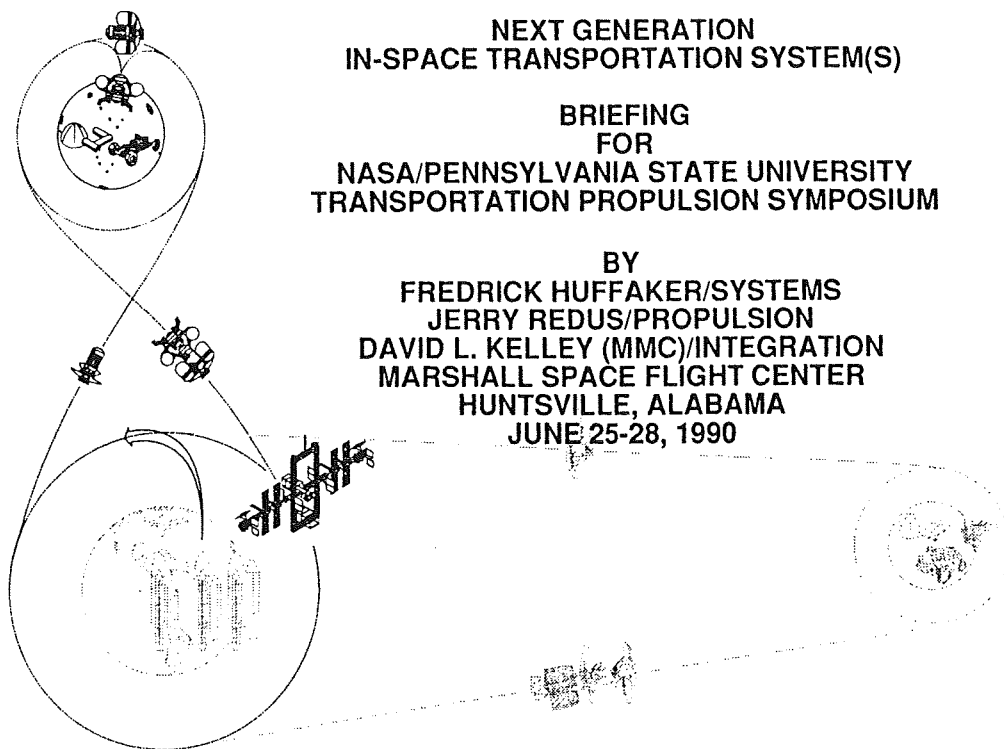


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**NEXT GENERATION  
IN-SPACE TRANSPORTATION SYSTEM(S)**

**BRIEFING  
FOR  
NASA/PENNSYLVANIA STATE UNIVERSITY  
TRANSPORTATION PROPULSION SYMPOSIUM**

**BY  
FREDRICK HUFFAKER/SYSTEMS  
JERRY REDUS/PROPULSION  
DAVID L. KELLEY (MMC)/INTEGRATION  
MARSHALL SPACE FLIGHT CENTER  
HUNTSVILLE, ALABAMA  
JUNE 25-28, 1990**

## **NEXT GENERATION IN-SPACE TRANSPORTATION SYSTEM**

### **Abstract**

The development of the next generation In-Space Transportation System presents a unique challenge to the design of a propulsion system for the Space Exploration Initiative (SEI). Never before have the requirements for long-life, multiple mission use, space basing, high reliability, man-rating and minimum maintenance come together with performance in one system that must protect the lives of our space travelers, support the mission logistics needs and do so at an acceptable cost. The challenge before us is to quantify the bounds of these requirements. The issue is one of degree. How long is an acceptable life in space? When does reuse pay off? To what degree is space basing practical; full, partial or expended? These are issues that determine the reusable bounds of a design and include dependability, contingency capabilities, resiliency and minimum dependence on a maintenance node in preparation for and during a mission. Missions to planet earth, other non-NASA missions and planetary missions will provide important but less demanding requirements for the transportation systems of the future.

The missions proposed for the Space Exploration Initiative will require a family of transportation vehicles to meet the requirements for establishing a permanent human presence on the moon and eventually on Mars. Specialized vehicles will be needed to accomplish different phases of each mission. These large scale missions will require assembly in space and will provide the greatest usage of the planned integrated transportation system. This paper looks at the current approach to defining the In-Space Transportation System for the SEI moon missions with later Mars mission applications. It reviews several system development options, propulsion concepts, current / proposed activities and outlines key propulsion design criteria, issues and technology challenges for the next generation In-Space Transportation System(s).



UPPER STAGES

## NEXT GENERATION IN-SPACE TRANSPORTATION SYSTEM

Space Transportation and Exploration Office

### AGENDA

- INTRODUCTION
- PROGRAM SCHEDULE (PLANNING)
- IN-SPACE TRANSPORTATION SYSTEM INTERFACES
- LUNAR TRANSPORTATION REQUIREMENTS (OPTION 5)
- PROGRAM DEVELOPMENT OPTIONS / CURRENT CONCEPT STATUS
- PROPULSION CONCEPT APPROACH
- ENGINE DEVELOPMENT CRITERIA
- TECHNOLOGY ISSUES
- PROPOSED ACTIVITIES
- CHALLENGE / SUMMARY

## SPACE EXPLORATION INITIATIVE PROGRAM SCHEDULE (Preliminary)

The Space Exploration Initiative proposed by President Bush will expand human presence and activity into the solar system including the moon and Mars. This means permanent human presence in space. Several architectures are currently under evaluation by NASA to determine how to best accomplish this objective. A reference architecture, Option 5, was used in our '90 Day In-House Study' activities in 1989. The Option 5 schedule is Figure 1 and shows the milestones for the Exploration Program and Technology Development against the Space Station Freedom accommodations. For Exploration, the program phases support a mission decision for the moon in FY93 and for Mars in FY01.

For the lunar mission, Phase A studies continue through FY92 with Phase B in FY93 & 94 leading to a Phase C / D in FY95 and the first manned Lunar flight in FY04. This calls for a major technology / advanced development program over the next 5 years leading to a lunar technology decision in FY95.

This paper will present a status of the In-Space Transportation System concepts, propulsion concepts, preliminary propulsion design criteria and the technology issues and challenges associated with the next generation In-Space Transportation Systems.

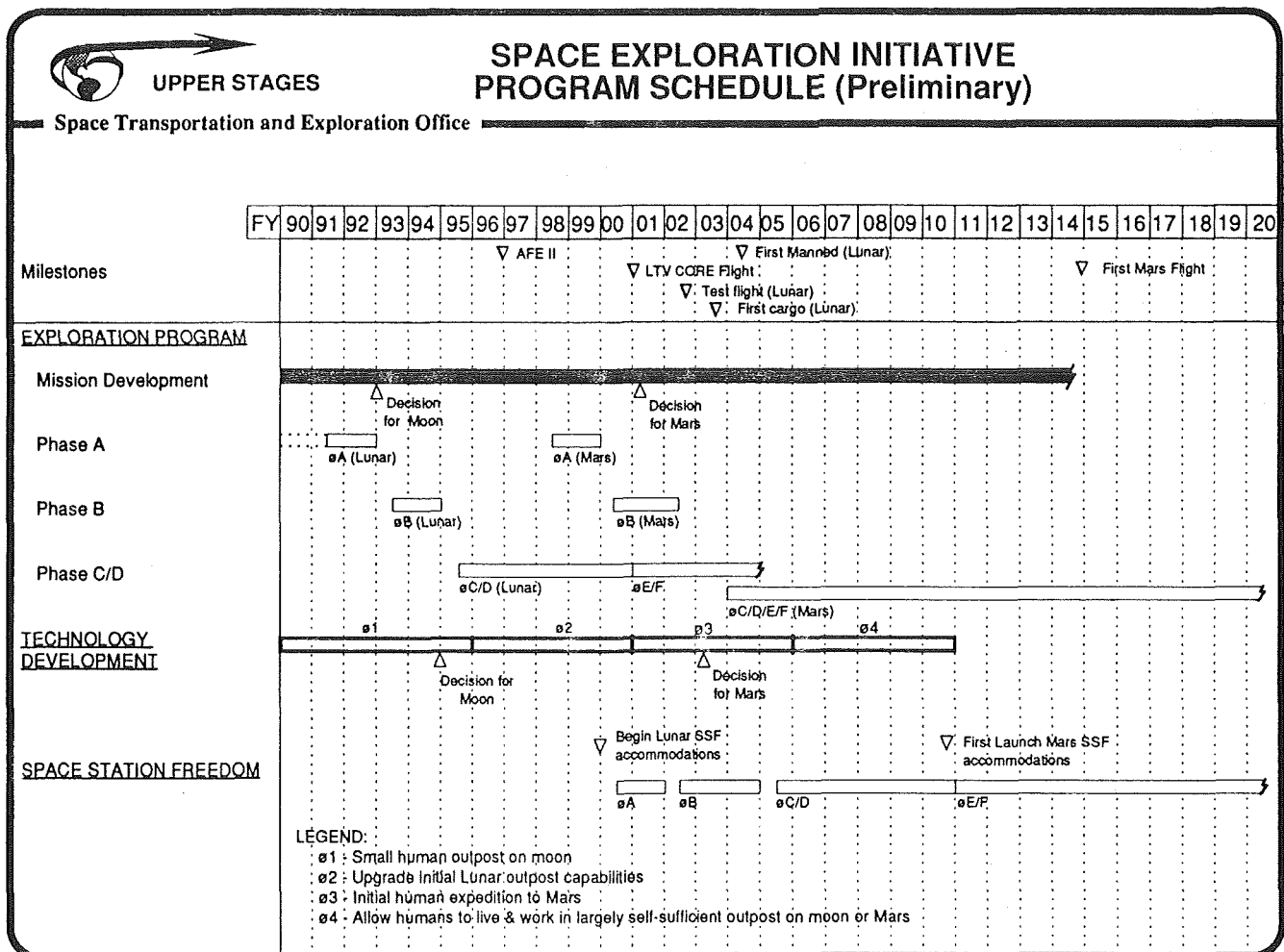


Figure 1

## IN-SPACE TRANSPORTATION SYSTEM INTERFACES

The many In-Space Transportation System interfaces are illustrated in Figure #2 and shows other center involvement, proposed and on-going study and technology / advanced development activities and the other Lunar/Mars Infrastructure elements i.e. Planetary Surface System (PSS), Earth-To-Orbit (ETO), Space Station Freedom Node for the Space Exploration Initiative (SEI) Program. The Integrated Transportation System activities interface with each and will have a major influence on those specific designs, supporting infrastructure and the overall future technology development program.

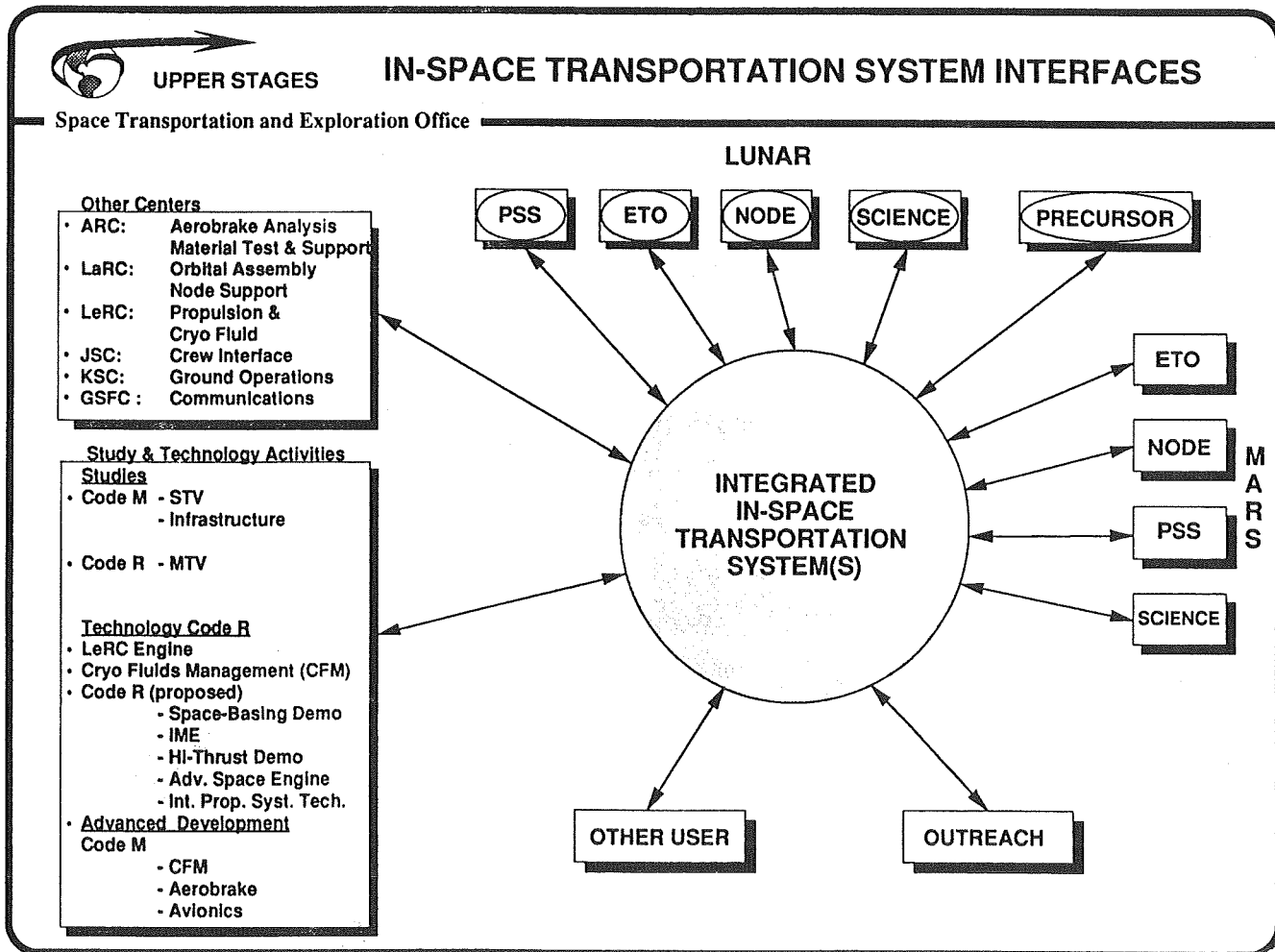


Figure 2

### EXPLORATION PROGRAM REQUIREMENTS (OPTION 5)

The top level mission requirements are summarized in Figure #3 for the moon (option 5). (The Mars mission requirements are not presented here.)



UPPER STAGES

### EXPLORATION PROGRAM REQUIREMENTS (OPTION 5)

Space Transportation and Exploration Office

#### COMMON (LTV/LEV)

- ONE FLIGHT/YEAR; REUSABLE 5 FLIGHTS! MINIMUM MAINTENANCE
- ASSEMBLY, MATING & CHECKOUT AT FREEDOM
- CARGO ONLY AND PILOTED MODES
- CREW OF FOUR; SHIRT-SLEEVE ENVIRONMENT
- MICROMETEOROID PROTECTION (FREEDOM PROVIDES DEBRIS PROTECTION)
- AUTOMATED RENDEZVOUS/DOCKING; CREW-CONTROLLED ON PILOTED FLIGHTS
- TWO HLLV FLIGHTS/YEAR (STEADY STATE)

#### LTV

- 180 PLUS DAYS MISSION LIFE; RADIATION PROTECTION
- FREEDOM BASED

#### LEV

- 180 DAY STAY AT LUNAR BASE; 180 DAY STAY IN LLO
- LUNAR LANDING
- 14t TO LUNAR SURFACE (33t EXPENDABLE)

Figure 3

## PROGRAM DEVELOPMENT OPTIONS

Shown are three basic program development options for the next generation In-Space Transportation System(s). The technology, timing and the development approach to vehicle evolution are significantly different for each.

The first (I) starts with the simplest and progress to more complicated vehicles. This was the approach of earlier Orbital Transfer Vehicle (OTV) studies. It begins with low technology and evolves with improved technology to the moon and ultimately to the Mars family of vehicles. This is a maximum evolution path incorporating new technology in progressive steps for the moon and later Mars vehicles.

The second (II) is to start with a primary objective of designing for the Lunar transportation requirements and evolve backwards and forwards to satisfy the other missions. Selected high leverage technologies applicable to later Mars missions are emphasized early i.e. propulsion, aerobrake. This is the selected approach under study now as part of the Space Transfer Vehicle (STV) Code M studies. Initial vehicle concepts could include design 'scar' for simpler and earlier expendable missions.

The third (III) is to start with a primary objective of Mars for designing the transportation system(s) and accepting the design impacts for Lunar and other missions. This approach is under study as part of the SEI Code R study.

Each option will be evaluated against and driven by the SEI goals and requirements. The difference is which (if any) is optimized. The challenge is to define what technology and timing best fit each program.

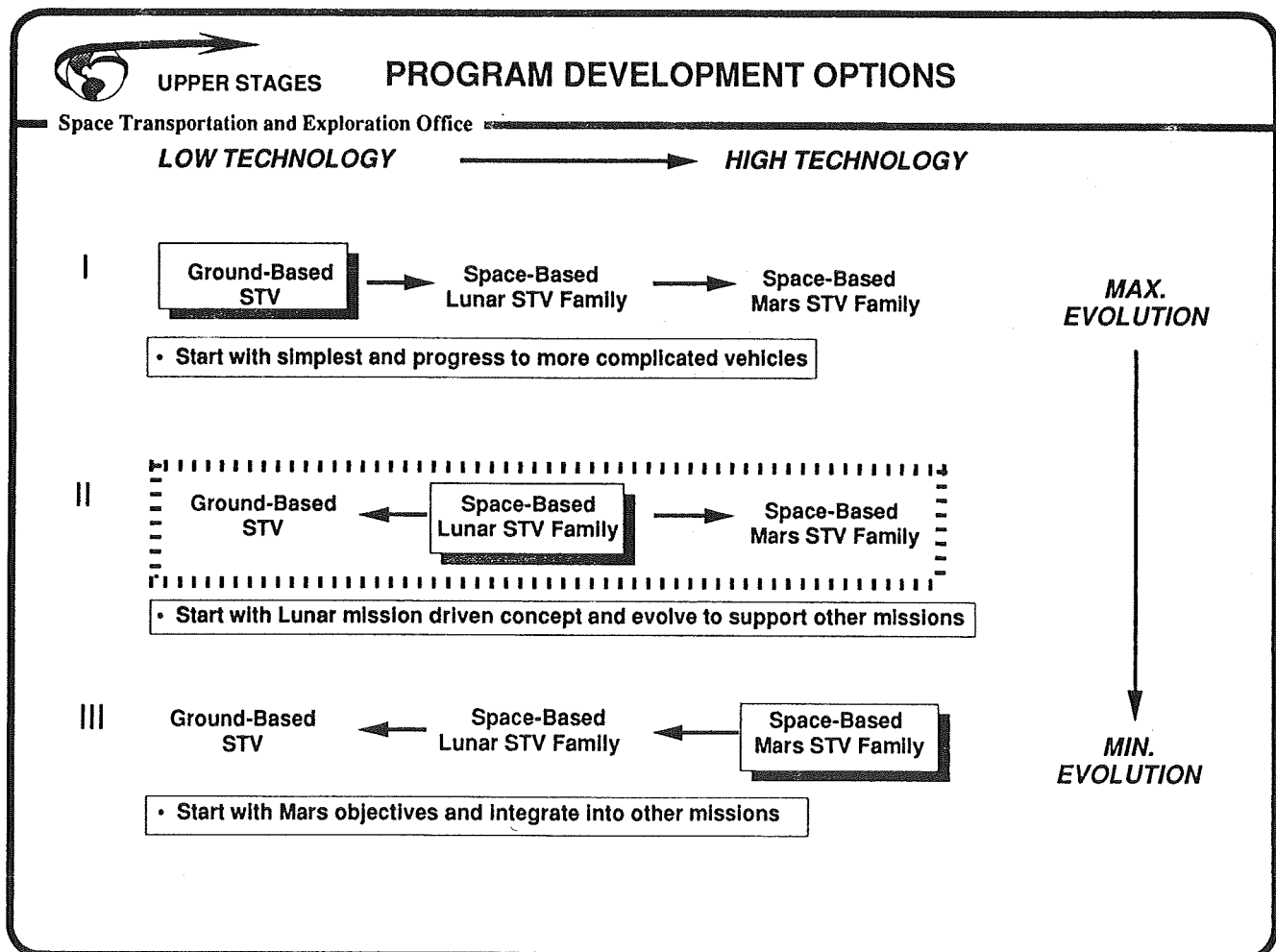


Figure 4

### LUNAR TRANSPORTATION SYSTEM (90-DAY STUDY REFERENCE)

The Lunar Transportation System (LTS) was designed, in the 90 day study, to carry 15t of cargo to the lunar surface in the piloted mode and 32t in the cargo (expendable) mode (Figure 5). The LTS consists of the Lunar Transfer Vehicle (LTV) and the Lunar Excursion Vehicle (LEV). The LTV consists of an earth-returnable, reusable core containing a crew module, core systems and an aerobrake, and four (4) propellant tanks that are dropped when expended. The LEV shares common core systems with the LTV and provides the specialized systems for landing and returning cargo from the lunar surface.

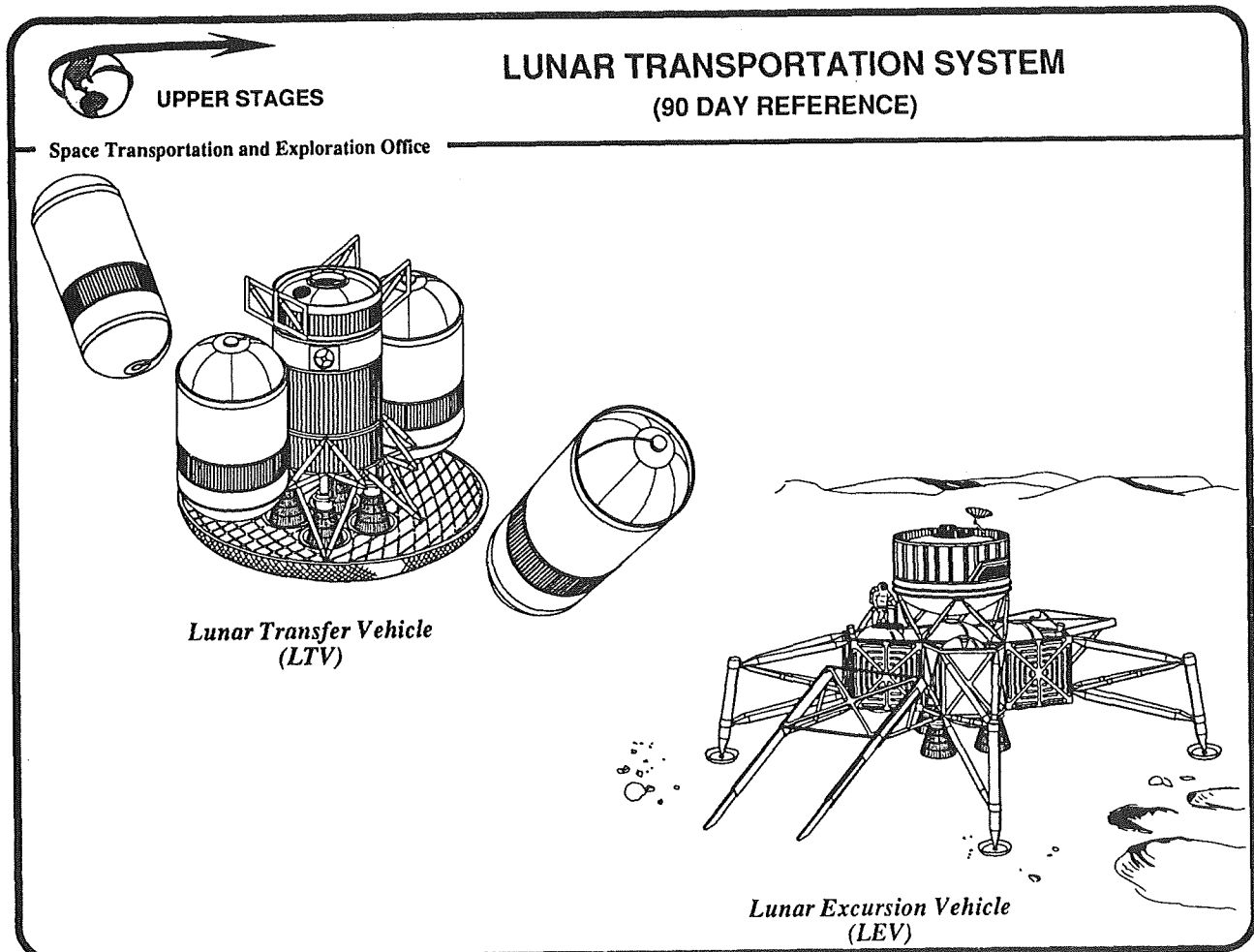


Figure 5



## LUNAR TRANSPORTATION OPERATIONS (90-DAY STUDY REFERENCE)

The Lunar Transportation System (Figure 6) is assembled at Space Station Freedom and is launched to the moon by the LTV propulsion system (1). Two TLI tanks are expended after the TLI burn (2). The LEV performs rendezvous and docking with the LTV after it achieves lunar orbit, refuels from the LTV, picks up the arriving cargo and/or exchanges crew (3). The LEV separates from the LTV and delivers the crew and cargo to the lunar surface (4). The two remaining empty tanks are dropped to the lunar surface by the LTV. The LTV then initiates TEI maneuvers and returns to earth orbit for rendezvous and docking with Freedom.

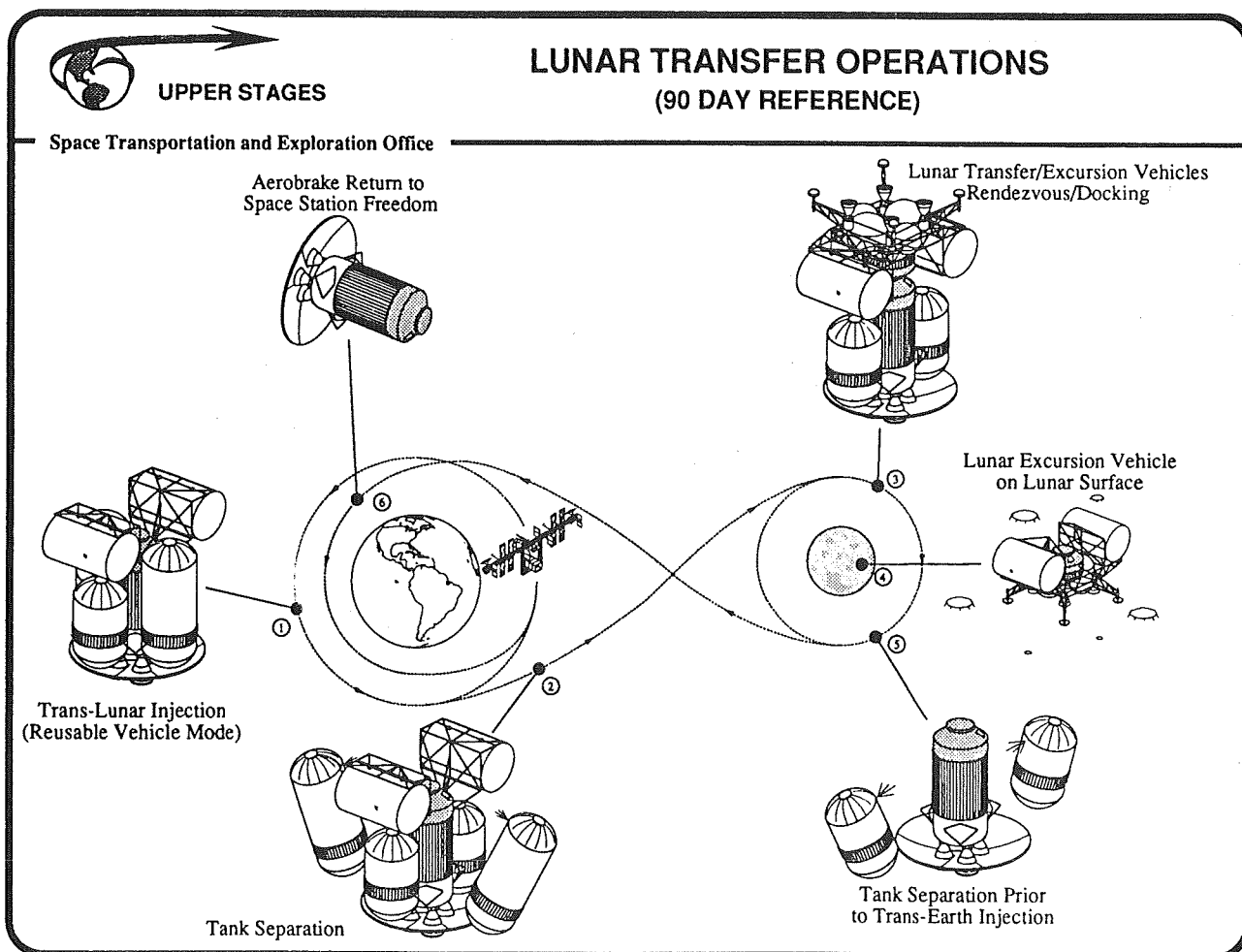


FIGURE 6

### PROPULSION CONCEPTS INFLUENCED BY NODE SELECTION

First, the propulsion concept is influenced by the assembly node selected. Chemical propulsion is common to most nodes under consideration and is the most likely propulsion concept for the first decade of the 21st century. As the node location moves further away from earth, the alternative nuclear propulsion concepts become more attractive but, the perceived safety problem of operating a reusable nuclear propulsion system routinely out of and into low earth orbits will be a most difficult problem to overcome.

Second, the sequence and timing of the SEI program as outlined by President Bush (i.e., First Freedom, Return to the Moon and then to Mars) establishes Freedom's availability for the transportation assembly node for Lunar missions. However, on-orbit assembly is only enhancing for Lunar missions but for Mars, on-orbit assembly is enabling. For Lunar we are still evaluating the degree of Freedom use as a transportation node.

Third, Mars Transportation Systems will be enhanced with nuclear propulsion; but chemical propulsion is envisioned as continuing to play a major role in the future Mars missions as well.

Four, major emphasis needs to continue for alternative chemical propulsion technology concepts to best satisfy the Lunar and later Mars missions.

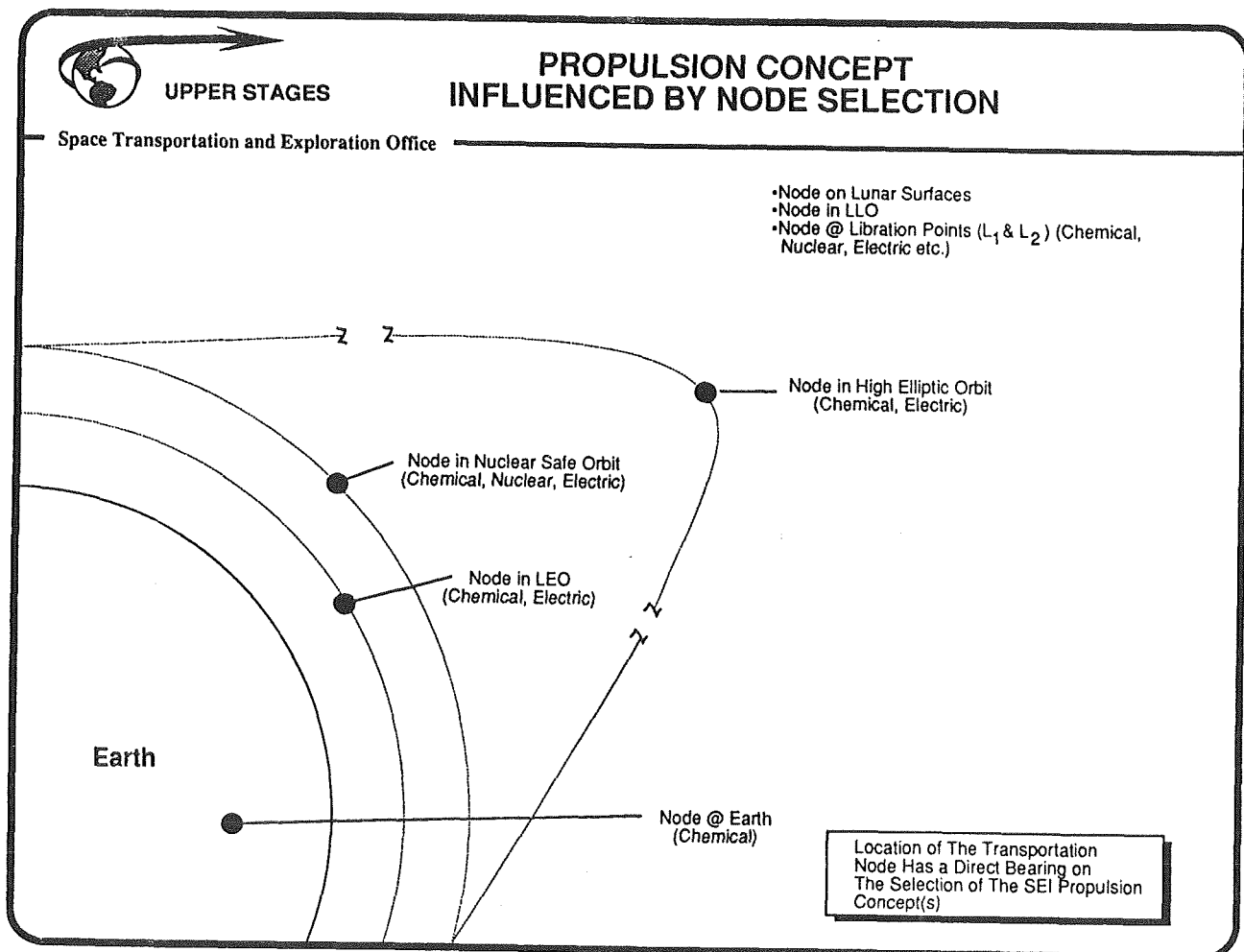


FIGURE 7

## PROPULSION CONCEPT APPROACH

Configuration trades for delivering SEI payloads fall into two categories: 1) Common cargo and crew vehicles or 2) Alternatives where the cargo vehicle is the same or different from the crew vehicle.

During the 'in-house' Human Exploration Initiative studies in late 1989, our approach placed emphasis on commonality for the individual mission requirements for cargo and crew on the same vehicle. Since then we have expanded to identify and conceive alternative conceptual configurations for cargo, combined and crew only missions to meet the Lunar, near earth, planetary delivery and Mars exploration requirements.

Figure 8 illustrates four propulsion types and several vehicle architectures and reusable options, with different evolutionary implications. Our current contractor studies are focusing on chemical (LO<sub>2</sub>/LH<sub>2</sub>) propulsion systems for the Lunar, mission earth, non-NASA, precursor, etc., mission requirements and applications for Mars Missions. (Other on-going studies are looking at broader alternative concepts i.e., nuclear, solar, electric, etc.)

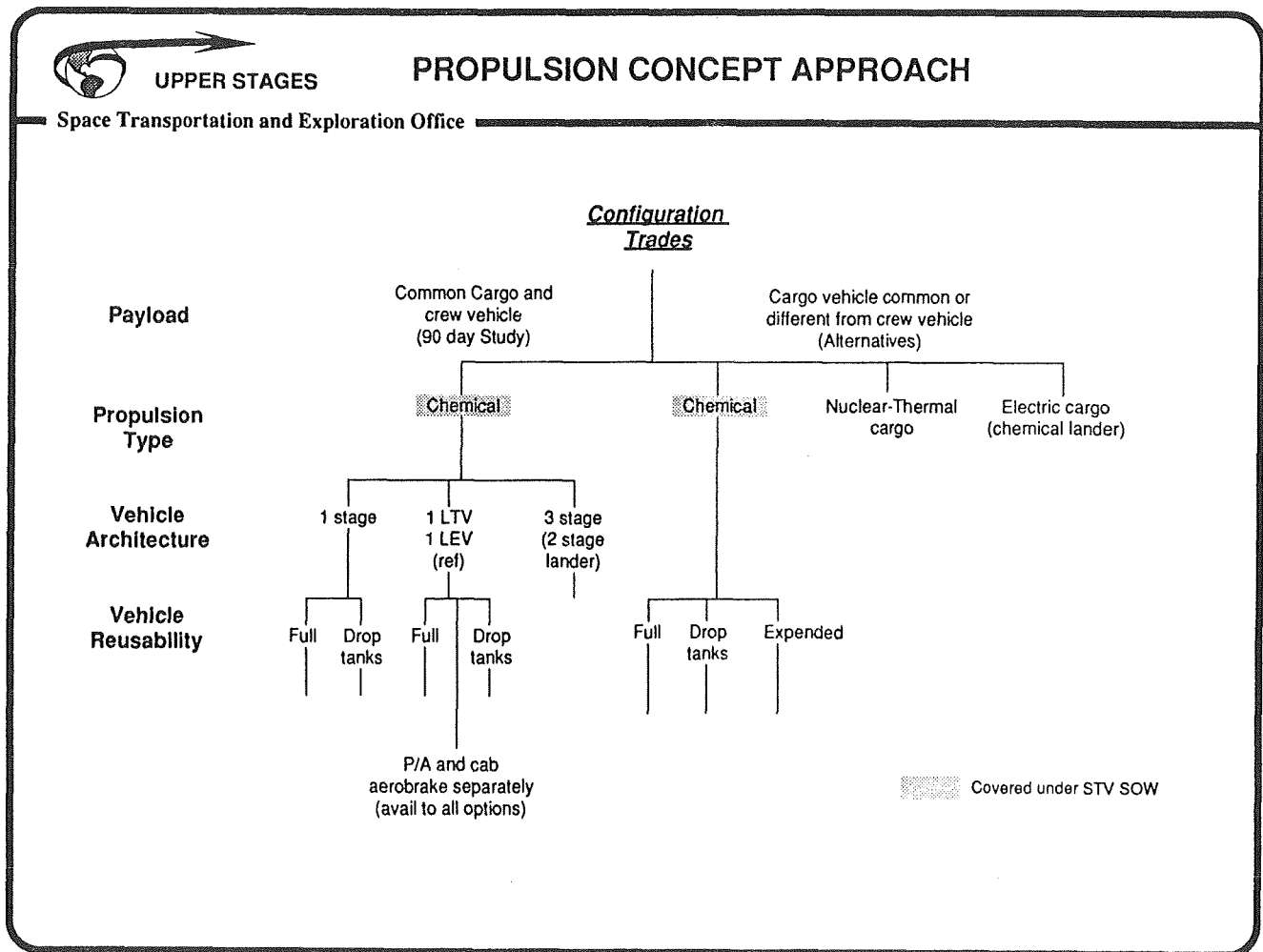


Figure 8

### Key Development Criteria for Next Generation Engine

The SEI program provides the opportunity to begin evaluating key development criteria for the next generation space engine. A preliminary list of engine criteria is shown on Figure 9. These criteria are presented in two parts: 1) Generic (all missions) and 2) Specific (mission dependent).

#### Reliable

High reliability is essential for dependable vehicle operations and safety for all missions. Reliability may be obtained by: redundancy or "robust" design or combinations of both, by an exhaustive test program or by improved subsystem component and interfacing reliability i.e., health monitoring sensors.

#### Space-Based

Space-basing is necessary for permanent human exploration missions and is based on:

- 1) the need for on-orbit assembly of the large Lunar or Mars Integrated Transportation System
- 2) reusability
- 3) the need for routine transportation to establish permanent human presence beyond earth's orbit.

From the vehicle viewpoint, the Integrated Lunar or Mars Transportation systems are large enough that final assembly must be accomplished in orbit. This will require the capability to mate, de-mate, inspect, test, refurbish, and maintain the vehicle before, during and after a mission.

From an engine viewpoint, the space-based engine will be designed for minimum maintenance, have a comprehensive health monitoring system utilized for pre-mission checkout, realtime safety monitoring and incipient failure mode identification, post-firing trend monitoring; and will be designed to withstand long exposures to the space environment.

#### Man-Rated

Man-rating is the process of evaluation and assuring that the hardware and software can meet prescribed, safety-oriented design and operational criteria. It is an integral part of the design, development, verification, management and control process and encompasses the complete design concept from Phase A to Phase E and F. It is characterized by: high reliability, failure tolerance, design and installation for contained damage, design or processing changes in response to failures, comprehensive test programs and crew interaction. Redundant components or engine-out capability may be required. The crew will be provided with fault detection, isolation and reconfiguration capability of critical systems.

#### Long-Life

As a goal, the vehicle / engine will be designed for five years or five mission life while exposed to the space environment. System / subsystem degradation must be incorporated into the design factors of the Integrated Transportation System. Material selection and development for space-based engines may emerge as an important design criteria after examination of the available data (particularly that from the Long Duration Exposure Facility, LDEF).

### Key Development Criteria for Next Generation Engine (Continued)

#### Engine Throttling

Engine throttling is necessary for accurate and safe landing. Throttling operations will require extensive study. It is not clear how fast the engine must respond to throttling requirements nor whether the engine must operate continuously over the full range or can pass through some ranges in a transient manner.

#### Vehicle / Engine Interface

Interfaces must be simple and reliable, commensurate with the space-basing requirement, but are otherwise subject to vehicle / engine trades. For example, turbopumps and combustion chambers might be manifolded for redundancy. This will place major emphasis on control, health monitoring and reliable diagnostic sensors.

#### Health Monitoring

A good health monitoring system capable of preflight, flight and post flight diagnostics, fault isolation, and safety monitoring is essential for a man rated, space-based engine. Whether the system is best lodged in a central vehicle data processing system, a propulsion system data processing system, or engine-mounted controller is not clear. Redundant data processing and storage may be desirable for some or all of the engine data.

#### Margins

High reliability will require a robust design, insensitive to operational conditions at the design point. Margins must be demonstrated by test, although this may not require test to destruction.

#### Performance

All performance specifications, including thrust, specific impulse (Isp), and mixture ratio are subject to trades. Size specification, primarily driven by gimbal angle requirements and fixed vehicle diameter, will influence the chamber pressure selection, expansion ratio, and Isp selection. The engine will probably be required to operate over some range of mixture ratios for efficient propellant utilization.



UPPER STAGES

## KEY DEVELOPMENT CRITERIA FOR NEXT GENERATION ENGINE (Preliminary)

Space Transportation and Exploration Office

	<u>CRITERIA</u>	<u>RATIONALE</u>
Generic for most Missions	* • Reliable • Space-Based	• No critical failure during each mission or subsequent-mission. • Necessary for: 1) On-Orbit Assembly of Integrated Lunar or Mars Transportation Systems and 2) Reusability without return to earth. (Designed for no planned maintenance). • Dependable and allow for emergency recovery.
	* • Man-Rated • Long-Life	• Five years or 5 mission life while exposed to the space environment. (Material degradation characterized and included in design).
	* • Engine Throttling	• Necessary for landing.
	* • Vehicle / Engine Interface	• Permits automated engine installation and removal by remote manipulator system, including built-in interface test equipment (eg. leak detection).
	* • Health Monitoring	• Necessary for pre-mission checkout, realtime safety monitoring and incipient failure mode identification and post-firing trend monitoring. It must be designed to withstand long exposure to the space environment.
Mission Dependent & Subject To Trades	• Margins	• Insensitive to operating conditions at the design point
	• Performance	• Subject to trades
	• Operations	• Operate for varying duty cycles after years of exposure to space environment
	• Engine Configuration	• Subject to trades
	• Other items useful to define engine characteristics	• Subject to trades

Legend: \* - Emerging technology needed for the SEI cryo engine

Figure 9

### EMERGING VEHICLE / ENGINE TECHNOLOGIES

Five technology challenges are emerging as a result of the vehicle / engine criteria development workshop and the STV Concepts and Requirements Studies currently underway. These technologies are:

- Space basing
- Long-life (material development and processes)
- Engine Throttling
- Vehicle / Engine Interface
- Health monitoring and control

Although an explicit technology requirement cannot be identified at the present, technologies that provide "robustness" and minimize health monitoring system reliability are sought. This is a high payoff area of sensor technology.

Other technology areas are expected to emerge as the vehicle, engine and vehicle / engine interface definition emerge. These development criteria and emerging technology reflect the need to reduce the cost of launching and expendable hardware and to establish a high confidence that later, longer duration missions to Mars will be successful.



UPPER STAGES

### **EMERGING VEHICLE / ENGINE TECHNOLOGIES**

Space Transportation and Exploration Office

#### Code R Technology Thrust (Propulsion-Related)

Aerobraking

Space-Based Engines

Vehicle Structures & Cryo Tanks

Cryogenic Fluid Systems

Vehicle Servicing & Processing

InSitu Resource Utilization

Nuclear Thermal Propulsion

Nuclear Electric Propulsion

#### Emerging Technology (From Engine Workshops)

Long Life (Material Development and Processes)

Vehicle / Engine Interfaces

Health Monitoring & Control

Diagnostic Sensors

Alternate Chemical Propulsion (IME)

Figure 10

## SPACE-BASED ENGINE TECHNOLOGY ISSUES

### Vehicle/Engine

The approach to Man-Rating should focus on increasing reliability of components, manufacturing processes, and sensor technology. The current systems should be improved before we start adding additional "bells and whistles." Extensive health monitoring should not be used as a substitute for high design margins. Increasing sensor reliability is critical to improving health monitoring. Design engine with margin for growth in thrust. Thrust growth should be anticipated before development and then that value must not be exceeded. Performance, operation and structural margins should be established for maximum anticipated vehicle demand and should be maintained during adjustments to mission requirements. That is, margins should never erode below normal levels to meet future growth requirements.

### Nozzle

Work is needed to develop light weight high reliability nozzle extensions. Extendable/retractable nozzles will be required for launch packaging, aerobrake maneuvers, and landing of some transportation concepts under consideration.

### Turbo Pump Assemblies (LH2 and LOX)

Technology work in the turbo pump area is critical to the success of the Advanced Space Engine. Low NPSP pumps are needed to have the most efficient vehicle design because inlet pressure can drive tank design. These pumps will need to be lightweight, compact, and very reliable to meet the mission requirements. The pumps will need to be designed for long life (5 years) with many restarts (100) and operate over a wide throttling range (20:1).

### Combustor

Technology work is needed on the Thrust Chamber Assembly (TCA) because of the unique operating environment the ASE will be subjected to; the ASE must be capable of starting on gas/gas, gas/liquid or liquid/liquid. It must be capable of long life with many restarts, high efficiency with throttling, high reliability, and have low  $\Delta P$  injectors for tank head starts. With the expander cycle design and high chamber pressures which require technology work.

The ASE engine will be very beneficial to the SEI program and as described here requires a concentrated technology effort to realize the goal of an efficient, highly reliable engine which can contribute to the LTS and MTS vehicles.



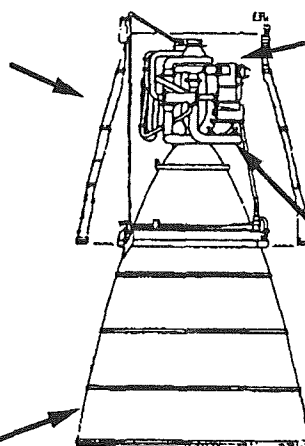
UPPER STAGES

## SPACE-BASED ENGINE TECHNOLOGY ISSUES

Space Transportation and Exploration Office

### VEHICLE/ENGINE

- Space Basing
- Man Rating Approach
- Reusability/Long Life
- Health Monitoring
- Materials



### TURBO PUMP ASSEMBLIES (LH2 & LOX)

- Low NPSP Pumps
- Lightweight/High Efficiency Pumps
- Turbine Drive Cycle (Expander, Gas Generator, Staged Comb.)
- High Reliability
- Health Monitoring
- Long Life w/Many Restarts
- Space Maintenance
- Throttling

### COMBUSTION

- Health Monitoring
- Long Life w/Many Restarts
- Space Maintenance
- Throttling
- High Combustion Efficiency
- Low Injector  $\Delta P$
- High Chamber Pressure (900-1500 psia)
- Low-Cost Chamber Materials and Manufacturing Process
- Robust Chamber/Nozzle Regenerative Cooling Method

### NOZZLE

- High Expansion Ratio (Up to 1000:1)
- Low Weight Nozzle Extension
- Lightweight Deployable 2-Position Nozzle w/High Reliability
- High Isp (up to 490 Sec)

Figure 11



#### TECHNOLOGY / ADVANCED DEVELOPMENT-PROPOSED ACTIVITIES

A program to define and demonstrate an Advanced Space-Based Engine for future in-space transportation applications is in progress at LeRC. MSFC is proposing a space-based engine project to identify and demonstrate the technology necessary for space-basing modifications to existing technology necessary for space-basing modifications to existing low and high thrust engines (RL-10 and J2/J2S) and to investigate the feasibility of development of Integrated Modular Engine. These activities are being coordinated through engine workshops at MSFC. These workshops are bringing together the vehicle and engine communities in a common forum to develop a coordinated set of engine requirements. The workshops are also serving to focus the approaches to Integrated Propulsion System technologies in areas such as space-basing, philosophy, monitoring and control, integrated sub-systems approaches, advanced mechanisms, power systems approaches and requirements analysis approaches. LeRC and MSFC are also cooperating in the development of technologies for Cryogenic Fluid Management. The CFM projects are developing test-beds for cryo-tank hydrogen demonstrations at MSFC and for flight demonstrations of cryogenic transfer by LeRC (COLDSTAT).



UPPER STAGES

#### TECHNOLOGY / ADVANCED DEVELOPMENT

Space Transportation and Exploration Office

#### PROPOSED ACTIVITIES

- MSFC
  - Space-Basing Demonstrator
  - Integrated Modular Engine
  - Integrated Propulsion System Technology
  - STV Engine Workshop
- LeRC
  - Advanced Space Engine
- LeRC/MSFC
  - Cryogenic Fluid Management

### SPACE-BASING DEMONSTRATOR

This project will investigate the modifications necessary to update an RL-10 engine to space-basing requirements and demonstrate those capabilities in ground tests. Specific areas of investigation include sensors and data processing for automated pre-mission checkout, real-time failure monitoring and failure mode identification, post-firing trend monitoring, modifications to permit automated installation, purge elimination and reduction of non-propulsive consumables.



UPPER STAGES

### SPACE-BASING DEMONSTRATOR

Space Transportation and Exploration Office

- GOAL:**
- Identify and demonstrate the technology necessary for "Space-Basing"
- APPROACH:**
- (Based on the RL-10 expander cycle engine)
  - Identify the sensors and data processing required to automate the pre-mission checkout, realtime safety monitoring and failure mode identification, and post-firing trend monitoring
  - Identify modification to the vehicle interfaces to permit automated installation
  - Develop a test plan to minimize or eliminate consumable non-propulsive fluids
  - Implement the health monitoring system, modified vehicle interfaces and any minor modifications that would eliminate purges on an RL-10
  - Install the engine in a test stand employing the "space-based" interface. Do all necessary checkouts remotely, fire the engine, do post-firing hardware and data evaluation and repeat TBD times
  - Investigate reduction in non-propulsive consumables per test plan
- BENEFITS:**
- Using an existing expander cycle engine gives access to known FMEA/CIL, hazards analyses, and operating procedures on which to base the health monitoring effort
  - RL-10 has demonstrated benign failure behavior in case of errors in analyses
  - Use of existing engine permits rapid completion of technology program
  - RL-10 represents an inexpensive testbed for space-basing technology
  - The focus on changes to an existing system assures identification of minimum technology requirements

Figure 13

### INTEGRATED MODULAR ENGINE

The need to provide an engine with variable length and thrust, new strategies for redundancy and safety and one that is capable of being integrated with an aerobrake has fostered a new engine approach: the Integrated Modular Engine. This engine project will provide the technology necessary to confidently proceed in the 1990's with the development of a modular plug-nozzle liquid hydrogen oxygen expander cycle engine for future space exploration missions. This proof-of-concept test bed will validate design analysis methodologies and define optimum requirements and characteristics for the engine.



UPPER STAGES

## INTEGRATED MODULAR ENGINE (IME)

Space Transportation and Exploration Office

### Objective:

Develop and demonstrate the technology necessary to apply modular plug-nozzle engines for future space exploration missions.

### System studies to identify optimum engine system architecture

- Redundancy Management
- Differential Throttling
- Throttling Range

### Approach:

Establish best approach to multiple chamber vacuum ignitor

### Component technology development

- Throttleable Injectors
- Turbomachinery
- Utilize past work and LeRC work in area where possible

Design, develop and assemble IME breadboard

### Test

### Benefits:

Provide the technology base for an alternative engine system design which may integrate better with the space exploration vehicles and have improved system reliability compared with the baseline bell-nozzle engines

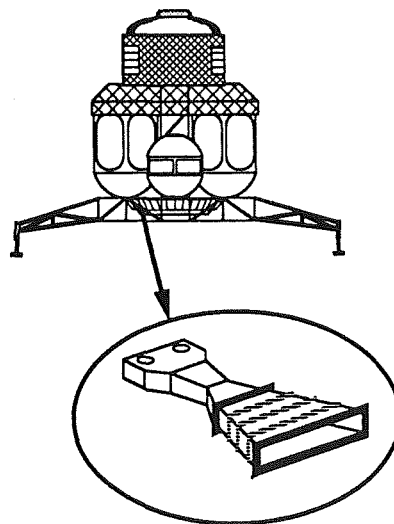


Figure 14

### CRYOGENIC FLUID MANAGEMENT

The handling of cryogenic fluids in low-g conditions poses many problems that affect how we operate space-based transportation vehicles i.e., engine start sequences, propellant settling, quantity gaging, tank fill and refill, tank chilldown, fluid transfer and residuals disposal. Operational work-arounds have been defined to resolve most of these problems with attendant operational inefficiencies. LeRC and MSFC are cooperating on a series of flight and ground tests to characterize CFM technology approaches and develop the procedures, operations, controls and instrumentation to enable design solutions for cryogenic fluid handling in future space transportation vehicles. These experimentation programs will develop the analytical models needed to define the parametrics in support of future propulsion system design.



UPPER STAGES

### CRYOGENIC FLUID MANAGEMENT

Space Transportation and Exploration Office

- Objective:** Define and develop experimentation to investigate the technologies for managing propulsion cryogenic fluids in space.
- Approach:**
- Systems studies to define requirements for cryogenic fluid management.
  - Definition of ground tests to investigate propulsion cryogenic fluid management technologies such as no vent fill, start baskets, venting approaches, insulation techniques, quantity gaging and residuals disposal.
  - Scaling data from 1-g tests to support extrapolation from LH 2 to LN 2 with simulation of LO<sub>2</sub> results.
  - 1-g Analytical Models.
  - Develop operations, procedures, controls and instrumentation.
  - Flight tests support scaling of 1-g models to low-g conditions.
- Benefits:**
- Reduction of operational work-arounds (i.e., acceleration settling of fluids)
  - Simple vehicle operations; fluid disposal, engine start sequences, quantity gaging, fill/refill, tank chilldown and fluid transfer.

Figure 15

### **INTEGRATED PROPULSION SYSTEM TECHNOLOGY**

The development of requirements for the transportation vehicle and its engines must provide an architecture that provides coordinated design approaches for common systems such as power and fluids. Coordination of common systems requirements and the implementation of these requirements in vehicle or propulsion systems that most efficiently serves the integrated transportation systems needs will reduce overall vehicle weight and redundant overlaps in system design. Potential design efficiencies in areas such as power generation, system monitoring and control, integrated cryo fluids systems and advanced mechanisms and the promise of reduced cost and weight warrant further efforts in this area.



**UPPER STAGES**

### **INTEGRATED PROPULSION SYSTEM TECHNOLOGY**

Space Transportation and Exploration Office

**Goal:** Define the requirements and technologies necessary to combine the vehicle and engines in an integrated propulsion system.

**Approach:** System studies to identify architectures for the vehicle and engines that will incorporate integrated design approaches in the following areas:

- Space Basing Requirements/Philosophy
- Propulsion System Monitoring and Control
- Integrated Cryogenic Subsystems
- Aerobrake Aperture/Closure
- Advanced Mechanisms
- Power for Propulsion Component (and Vehicle)
- Vehicle and Mission Requirements Analysis

**Benefits:**

- Integrated Vehicle/Propulsion design approaches
- Design efficiencies resulting in reduced weight and consumables
- Common development philosophies and lower cost

Figure 16

### STV ENGINE WORKSHOP

The NASA, vehicle systems contractors and engine contractors have met in April, 1990 to help focus the propulsion engine technology/advanced development program and also to help define criteria and trades with which to select the overall approach for the Space Transfer Vehicle propulsion systems. A preliminary set of top level criteria was defined for a space-based engine and key trades were identified. Another session of the workshop is planned for early August. The proposed topics are shown in Figure 17.



UPPER STAGES

## STV ENGINE WORKSHOP

Space Transportation and Exploration Office

### OBJECTIVE: Primary Emphasis -

- Help focus the propulsion engine technology programs
- Help select the STV concept
- Provide data for contractor and in house government studies
- Define the approach to the development of engine design criteria for the National Space Transfer Vehicle or family of vehicles

### ORGANIZATION:

Chairman: Fred Huffaker, MSFC/Program Development  
Co-Chairman: Jerry Redus, MSFC/Propulsion Laboratory

Vehicle Contractors: Boeing Aerospace  
Martin Marietta

NASA Centers: NASA Headquarters  
Lewis Research Center  
Kennedy Space Center  
Jet Propulsion Laboratory  
Johnson Space Center  
Marshall Space Flight Center  
Stennis Space Center

Engine Contractors: Aerojet  
Pratt & Whitney  
Rocketdyne

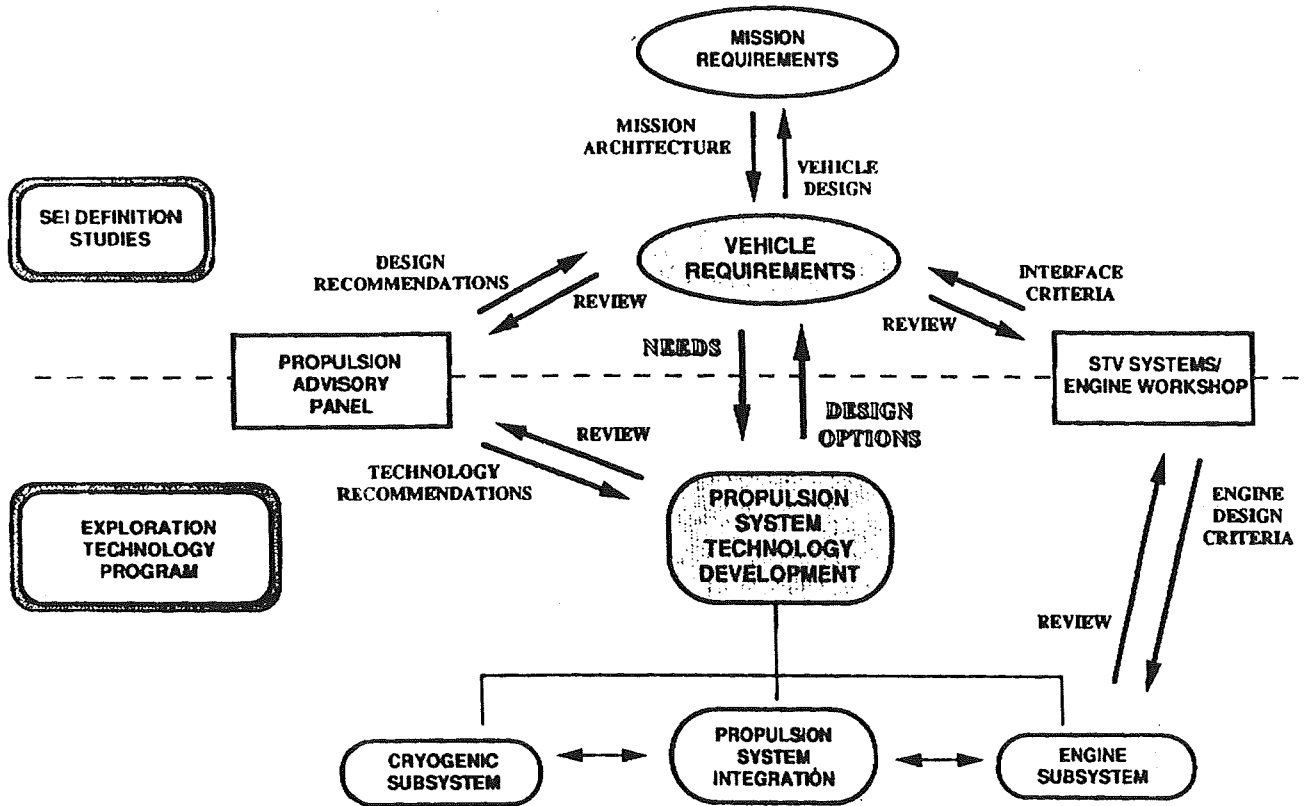
### PLANNED TOPICS AT SECOND WORKSHOP (MID-JULY, 1990)

Directed toward a limited number of key issues

- Space Environment and its effect on long-term use of materials as it affects engine life
- Operations (including mainline, maintenance, and contingency)
- Man-rating (demonstration technology and health monitoring)

Figure 17

## ETP CHEMICAL TRANSFER PROPULSION



#### PROGRAM CHALLENGE/SUMMARY

The development of the Next Generation Space Transportation Propulsion System presents a challenge unique to the aerospace program. Never before have the requirements for long life, space-basing, reliability, man-rating and minimum maintenance come together in one transportation system that must protect the lives of our space travelers, support the planetary logistic needs and do so at a reasonable cost. The use of robotics presents additional challenges and solutions to the propulsion designer. This presentation has put the issues "on the table" that must be resolved by the propulsion community. Proposed activities to define the vehicle system requirements and define engine test beds are supportive of future plans to conduct an integrated government/contractor propulsion development program.



UPPER STAGES

#### **PROGRAM CHALLENGE / SUMMARY**

Space Transportation and Exploration Office

- CHALLENGE:**
- Develop a Next Generation Space Transportation Propulsion System for the manned exploration of the planets
  - Develop a long life, space - based propulsion system that requires minimum maintenance, is reusable and is capable of repair with the use of robotics

- SUMMARY:**
- Preliminary definition of the system requirements in progress
  - Definition of preliminary propulsion criteria development process / trades / technology (planning group)
  - Issues "on the table" to challenge engine community
  - Testbeds defined and in work to identify and define engine characteristics (LeRC and MSFC)
  - Plans in progress to define and conduct an integrated government / contractor engine development program